PACIFIC OCEAN WAVE INFORMATION STUDY
VALIDATION OF WAVE MODEL RESULTS AGAINST SATELLITE ALTIMETER DATA

DRAFT REPORT

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1.0 INTRODUCTION

Baird & Associates was retained by the Engineering Research and Development Center of the U.S. Army Corps of Engineers to participate in the initial development of the Wave Information Study (WIS) hindcast wave climate for the Pacific Ocean. One task in this wave climate development was the inter-comparison of three different wave models, Wavewatch III, WAM Cycle 4.5 and WAVAD, using consistent input parameters, including model grids, wind fields and simulation settings. The comparisons were achieved through assessment of the accuracy of the computed wave conditions against both historical wave buoy data and satellite altimeter estimates of significant wave height. Although wave buoy data provided the primary means of assessing hindcast model skill, the use of satellite altimeter data gave insight into the spatial distribution of errors in the wave field.

All of the wave models utilized an input depth grid that encompassed the entire Pacific Ocean, extending over the region from 110°E to 60°W, and 64°S to 64°N, at a grid resolution of 0.5°.

This report summarizes the methodology and results for the satellite altimeter comparisons. Specifically, comparisons have been carried out for the Wavewatch III (WW3) and WAVAD models using Topex and Jason-1 altimeter data. Section 2.0 describes the quality procedures and wave height corrections applied to the altimeter data. In Section 3.0, the methodology for deriving the spatial comparisons is outlined. The results of the analysis are presented in Section 4.0.

2.0 QUALITY CONTROL AND CORRECTION OF THE SATELLITE DATA

2.1 Background

Satellite altimeter data has proven to be a very useful source of information for the calibration and validation of wave hindcast models. Although limited in the extent of data provided (significant wave height and wind speed primarily) and in the temporal resolution at any given location, altimeter data can provide an understanding of the spatial variability of wave model reliability and accuracy not readily available from wave buoy data. There are presently several satellite-borne altimeters that are operational. In this study, datasets derived from two satellite missions, the Topex/Poseidon and Jason-1, are employed.

The Topex/Poseidon satellite has been operational since 1992, and has provided thirteen years of continuous data. There are two different satellite altimeters on board: (1) a NASA dual-frequency Ku/C band radar altimeter and (2) an experimental CNES Solid State ALTimeter (SSALT). In this investigation, only Ku-band data from the NASA sensor has been utilized.

The primary (Side A) NASA altimeter was found to be subject to electronic drift starting at approximately cycle number 98 (Queffeulou, 2004), and was replaced by a secondary (Side B) altimeter in February 1999. The instrument drift and change-over in the sensor have been considered in the wave height estimates.

The Jason-1 satellite was launched on December 7, 2001 as a follow-on mission. The satellite was flown in tandem with the Topex/Poseidon satellite at the start of its operational period in order to cross-calibrate the satellite instruments, then the Topex/Poseidon satellite was shifted to a position between the Jason-1 tracks.

In this study, Topex data have employed for all wave height comparisons throughout the period of record of the WW3 hindcast (1995-2004) with the addition of Jason-1 data for comparisons from 2002 and onwards.

The Topex /Poseidon data were extracted from the Merged Geophysical Data Records (MGDR) Generation B, as obtained from the Jet Propulsion Laboratory of California Institute of Technology. The Jason-1 data were extracted from the Geophysical Data Records, obtained from the same source.

The extracted data were subjected to a variety of quality control procedures, as described in Section 2.1 below. Those significant wave height records passing the quality control step were then subject to final corrections. Finally, the corrected data were then compared to historical wave buoy measurements in the Pacific Ocean.

2.2 Quality Control Procedures

The altimeter data were subject to the following primary quality control tests. Records not passing these tests were discarded.

Topex

The record was discarded if:

SWH_Pts_avg <= 7

RMS_H_Alt > 100

Geo_Bad_1_Bit(0) = 1

Geo_Bad_1_Bit(1) = 1

Geo_Bad_1_Bit(3) =1

Geo_Bad_2_Bit(0) = 1

AGC_Pts_Avg < 16

H_ocs > -40

Jason-1

The record was discarded if:

SWH_Pts_avg <= 17

qual_1Hz_alt_data = 1

surface_type = 1

alt_echo_type = 1

rad_surface_type = 1

rain_flag = 1

ice_flag = 1

bathy > -40

SWH_RMS_K was subject to SWH dependent limits as per Queffeulou (2004)

As well, there were various secondary checks on data found close to land. Sensibility tests were applied to the SWH measurements, and the first record after any time gap in the dataset was discarded.

2.3 Significant Wave Height Corrections

Correction factors have been developed by various investigators to be applied to the altimeter data, as typically derived through wave buoy comparisons. In this study, following wave height corrections have been utilized, as per Queffeulou (2004):

Topex Side A

$Hs^* = 1.0539 * Hs - 0.0766$

For Cycle < 98: Hs_corrected = Hs^*

For Cycle ≥ 98: Hs_corrected = $Hs^* + F(98) - F(cycle)$

with

$F(x) = \Sigma (a_i * x^i)$

$a_1 = -6.0426E-4$

$a_2 = -7.7894E-6$

$a_3 = 6.9624E-8$

Topex Side B

H_corrected = 1.0237 * Hs – 0.0476

Jason-1

H_corrected = 1.0587 * Hs – 0.0571

where:

Hs is the significant wave height as derived from the altimeter data records,

Hs_corrected is the final, corrected significant wave height, and

Cycle is the Topex mission cycle number.

2.4 Data Validation

A brief validation study was carried out in which the corrected altimeter wave heights were compared to wave height measurements at various Pacific Ocean buoys. The results of this validation may be seen in Appendices A and B for Topex and Jason data, respectively.

Excellent agreement was achieved with the buoy data.

3.0 WAVE MODEL VALIDATION METHODOLOGY

The following is a brief summary of the steps involved in preparing the spatial wave height comparisons between the satellite altimeter and hindcast model data.

- The altimeter data, available at one-second intervals, was initially averaged over a ten-second time period in the along-track direction. This essentially provided an average of wave conditions over a 60 km path, compatible with the grid resolution of the wave models.

- The wave model significant wave height data, which was archived at 6-hour intervals, was interpolated in time and space to the averaged altimeter SWH data points.

- The resulting altimeter and wave model pairs of data were then collocated to an assumed regular grid encompassing the North Pacific Ocean at 1.5° resolution.

- Statistical parameters, such as bias, root mean square error, scatter index and correlation, were computed at each grid point for the collocated data. The bias is determined as the model values minus the measured values.

- One pass of spatial smoothing was applied to the statistical parameters.

- The active grid points with data were triangulated, and contour plots of the statistical parameters prepared.

4.0 VALIDATION RESULTS

4.1 Wavewatch III

Ten years (1995-2004) of wave hindcast data for the Wavewatch III model were provided as 6-hourly fields of significant wave height over the North Pacific Ocean region. Prior to the altimeter comparisons, basic spatial plots by year of mean and 1% exceedence significant wave height were derived, as shown in in Appendix C.

Appendix D provides yearly comparisons of statistical measures of hindcast accuracy. Appendices E and F contain similar comparisons but considering winter and summer months only, respectively.

4.2 WAVAD

The WAVAD model simulation covered the year 2000 only. Appendix G contains plots of statistical comparisons for winter months, summer months and the full year.

5.0 GENERAL OBSERVATIONS

General observations made from the results of the various comparisons conducted during this investigation are summarized below. These observations are not intended as a comprehensive assessment of the wave models as the satellite data comparisons need to be compared in context with other measures of model skill.

- It is important to recognize that the satellite comparisons were interpolated using six-hourly wave fields from the wave models. This will tend to result in increased scatter in the comparisons.

Wavewatch III

- The spatial plots of annual wave height statistics (Appendix C) show similar patterns from year to year; however, higher than average wave heights were estimated for 1995, 1998 and 2000 in the northern mid-latitudes of the Pacific Ocean.

- The comparisons to altimeter typically show a positive bias in the northeast Pacific Ocean. This bias is greater during certain years, such as 1995 and 1998. A relatively small bias was determined in the equatorial region. The bias is much larger in the winter than the summer.

- There are regions of zero and negative bias located within the North Pacific. These regions are generally found around island regions, such as Hawaii, where the effects of sub-grid blocking in the wave model are important.

- A high degree of correlation in wave heights is found throughout much of the North Pacific above the equatorial region. Relatively poor correlations are achieved in the eastern equatorial area, presumably due to inaccuracies in the wind fields.

- The plots of scatter index show considerable spatial variability.

- There are significant differences in the model comparisons between winter and summer. The winter comparisons show significantly greater bias, root mean square error, and scatter index values.

WAVAD

- The WAVAD results show a positive bias in the mid-latitudes of the North Pacific, but it is less pronounced than the Wavewatch III bias. There are regions of strong negative bias in the equatorial region. The region above the Aleutian Islands shows a strong positive bias, potentially associated with the leaking of energy through the sub-grid representation of the many islands in this region.

- The WAVAD model shows less correlation to the altimeter data than the Wavewatch III model.

- The WAVAD model exhibits less spatial variation in the scatter index values, but there are very high scatter indices in the west Pacific and above the Aleutian Islands.

6.0 REFERENCES

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